Operation Optimization of an Array of Receiver-Reactors for Solar Fuel Production

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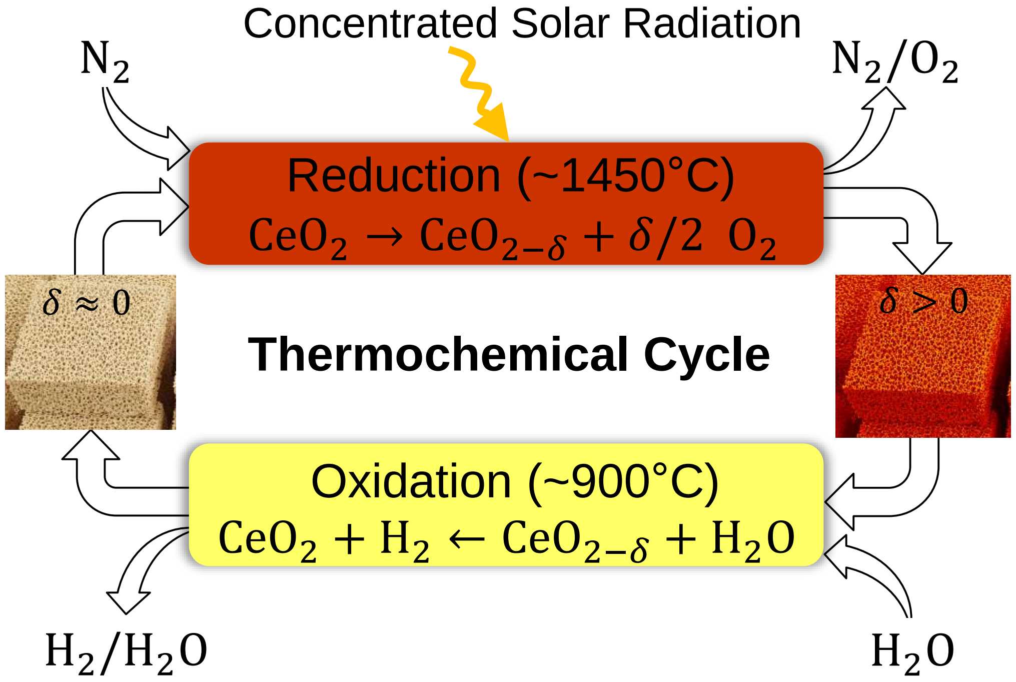
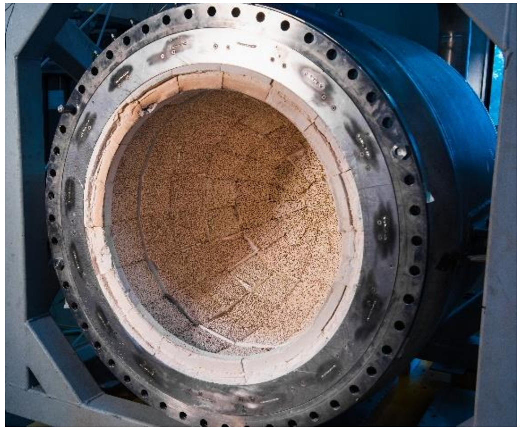
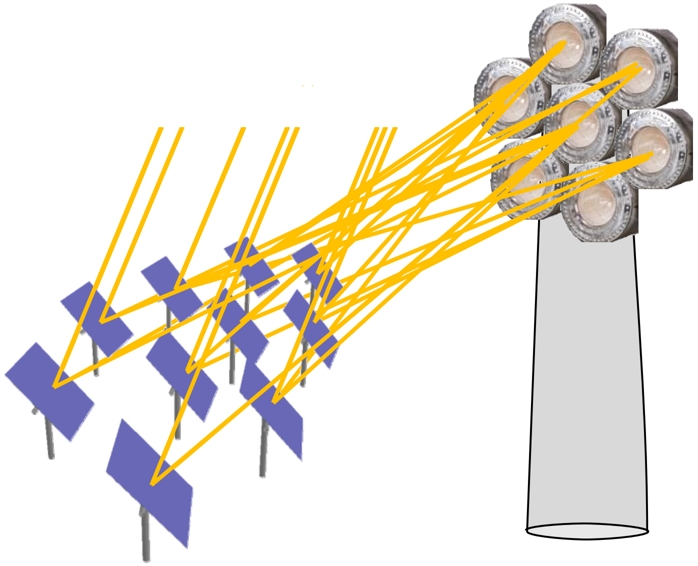
Motivation: Solar Thermochemical Hydrogen Generation



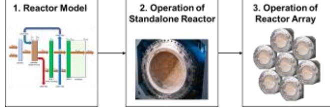
Reactor (window removed)



Scale Up: Multi-Reactor Plant

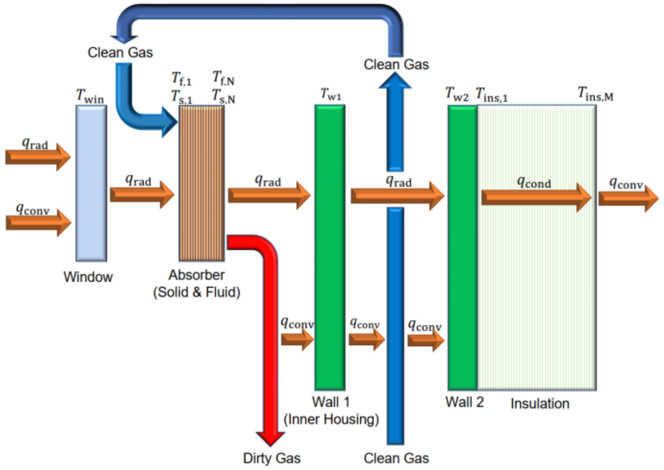


- How to operate each reactor?
- How to distribute the available power?



Approach and Outline

1. Reactor Model

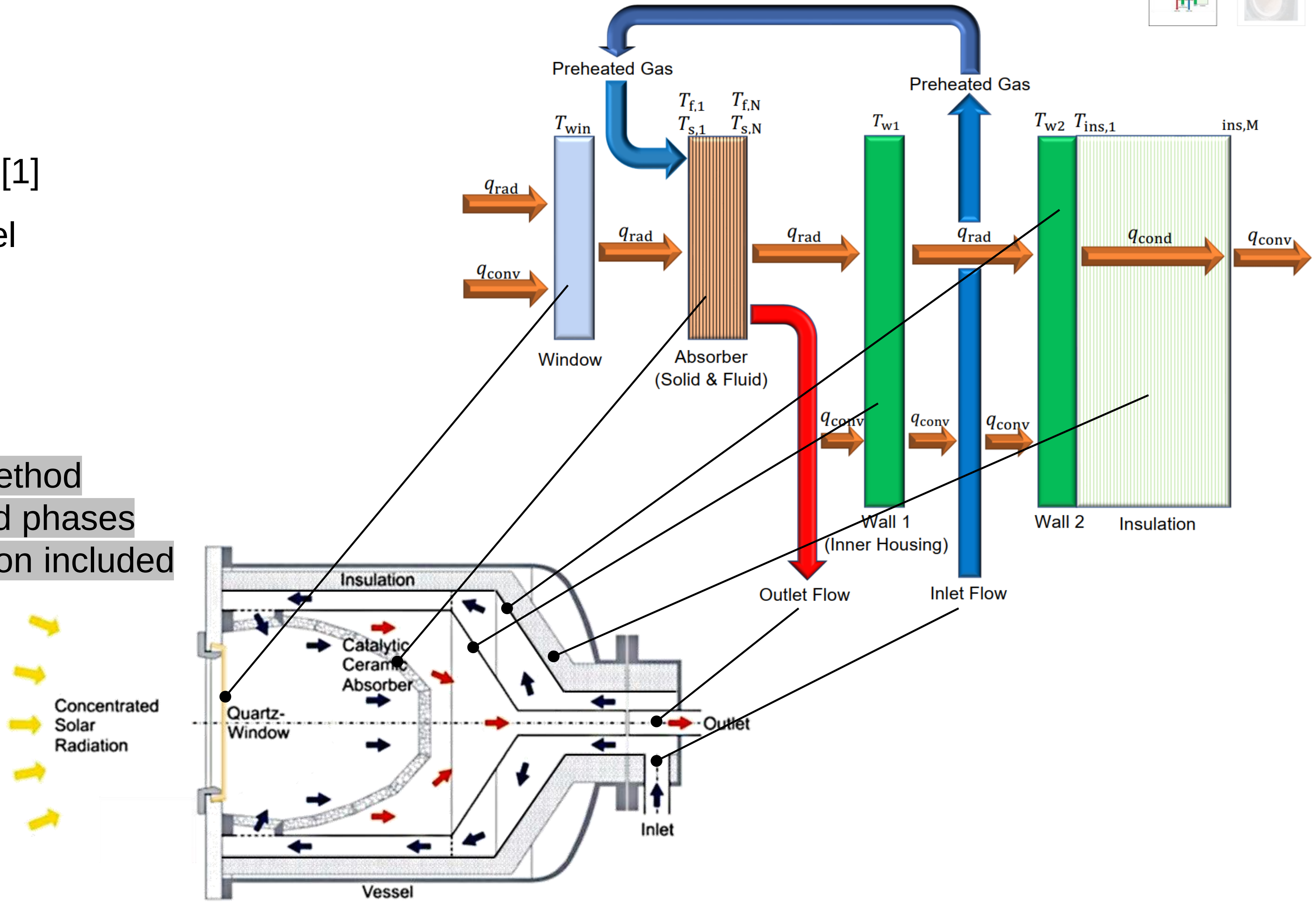


2. Operation of Standalone Reactor

3. Operation of Reactor Array

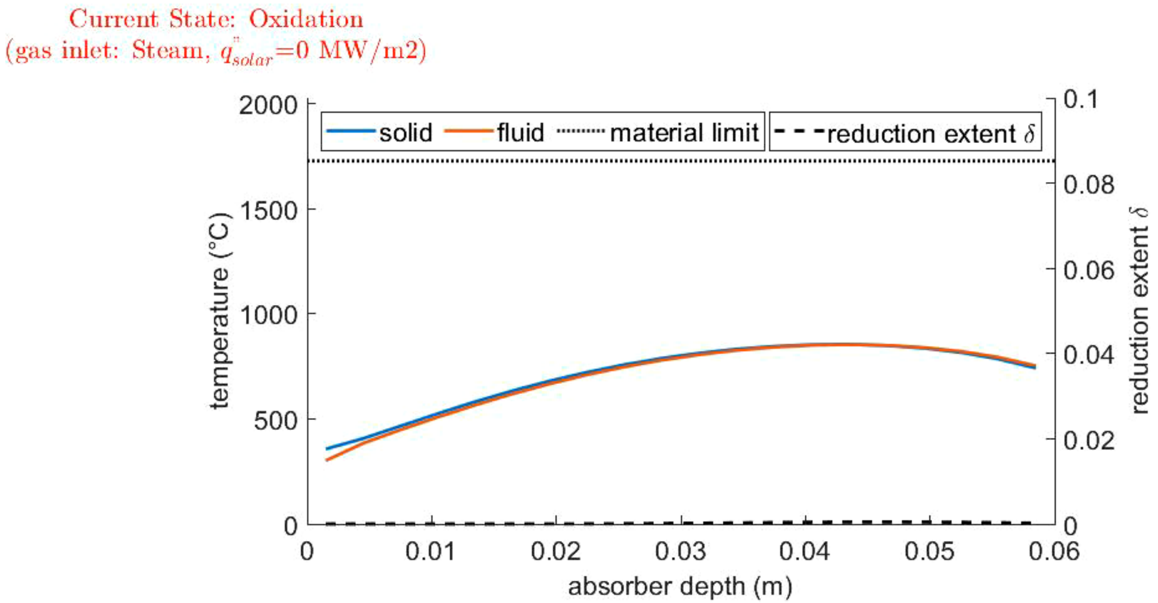
Reactor Model

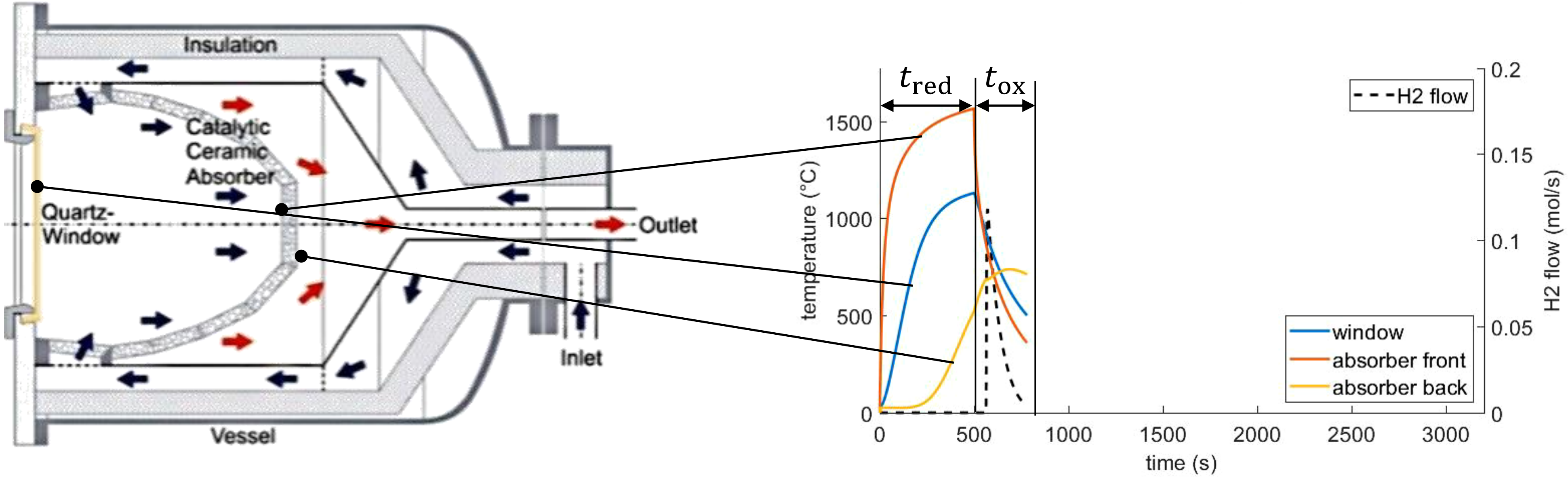
- Improvement of model in [1]
- Spectral view factor model
- Preheating of gas flow
- Insulation: 1D conduction
- Absorber:
  - 1-D finite volume method
  - Coupled fluid & solid phases
  - Reduction & oxidation included



[1] Lidor et al., Parametric investigation of a volumetric solar receiver-reactor, Solar Energy, 204, pp. 256-269, 2020

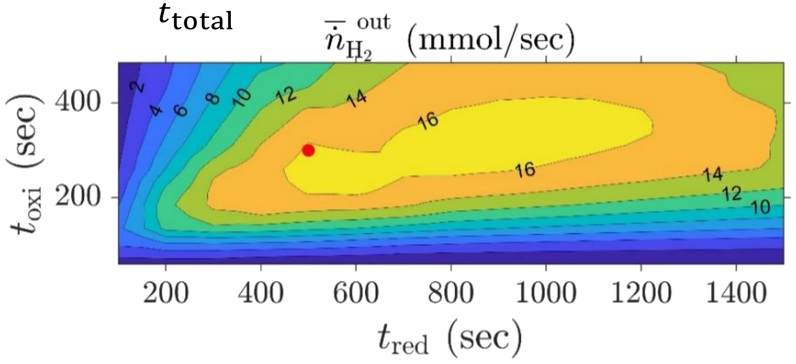
Reactor Cycle



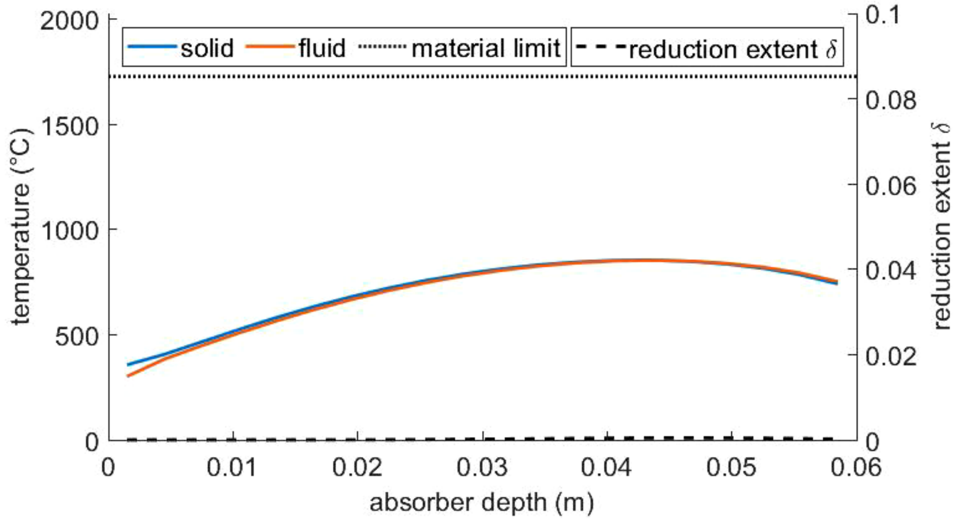


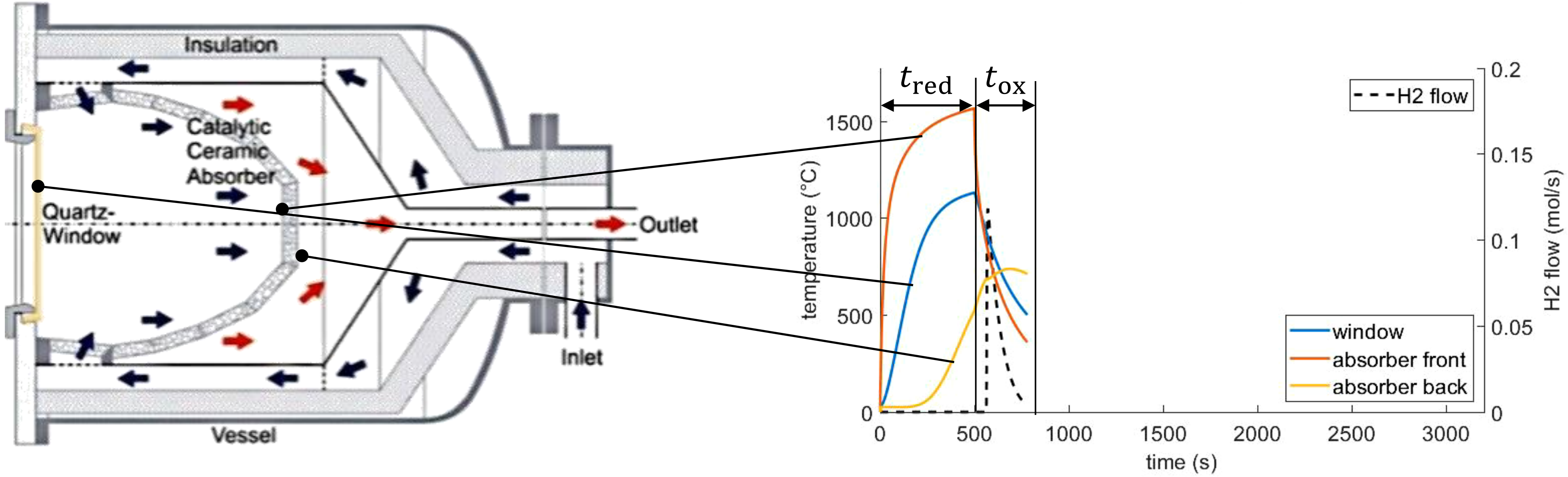
Reactor Cycle

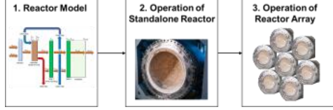
$$\bar{\dot{n}}_{\mathrm{H_2}}^{\mathrm{out}} = \int_{t_{\mathrm{total}}} \dot{n}_{\mathrm{H_2}}(t)\mathrm{d}t$$



Current State: Oxidation
(gas inlet: Steam, $\dot{q}''_{solar}$=0 MW/m2)

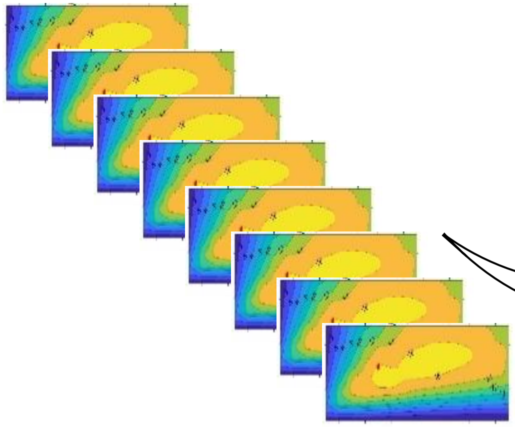






Multi-Chamber Operation

- Set the solar flux to zero during oxidation and keep it constant during reduction
- Find pair of reduction and oxidation time which gives highest hydrogen yield for a single, standalone chamber
- Do this for several solar fluxes at the aperture



Strategy	I	II	III	IV	V	VI	VII	VIII
q''_{rad} (MW/m²)	0,5	0,75	1,0	1,25	1,5	1,75	2,0	2,25
t_{red} (s)	1382	1018	843	237	102	62	47	35
t_{ox} (s)	293	296	307	235	155	133	139	126
η	0,3%	0,9%	1,6%	2,6%	2,8%	2,8%	2,9%	2,8%
$\bar{\dot{n}}_{\mathrm{H_2}}^{\mathrm{out}}$ (mmol/s)	2,0	7,6	16,7	23,0	23,5	21,8	20,7	19,7

3. Operation of Reactor Array

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Selecting Optimal Single Chamber Strategies

Strategy	I	II	III	IV	V	VI	VII	VIII
q''_{rad} (W/m²)	0,5	0,75	1,0	1,25	1,5	1,75	2,0	2,25
t_{red} (s)	1382	1018	843	237	102	62	47	35
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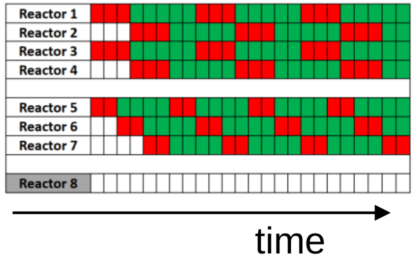
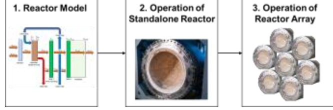
Shift Process Starts

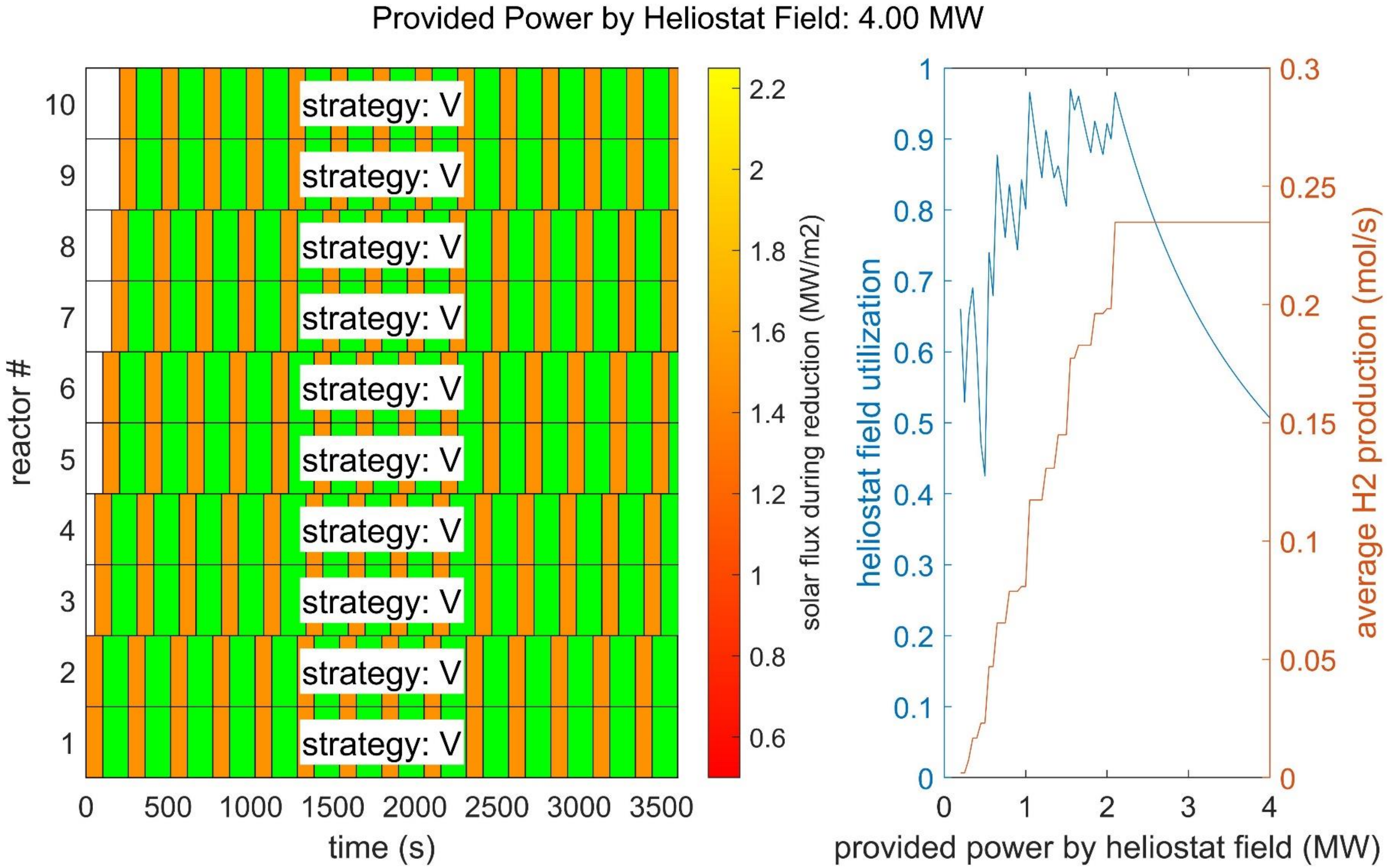


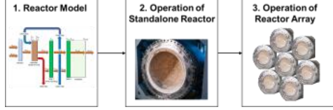


Multi-Chamber Process

Algorithm to shift process starts and to choose the strategy for each chamber

- Two groups of reactors
- In a group, all reactors follow the same strategy
- Process starts within a group are offset to minimize the required peak power
- Strategies within each group are varied and reactors are moved between groups
- Robust way to find a good multi-chamber operation mode





Summary

- Fast and robust way to find an operation strategy for multi-chamber reactors
- First approach, it will be improved:
    - Less simplifications (flexible solar flux, mass flow, cycle times)
    - More accurate representation of heliostat field with raytracing software
    - Integrate up- and downstream processes
    - Compare to other optimization approaches

Thank you for your attention!

- Questions? Write an email to the corresponding author: Johannes.Grobbel@dlr.de

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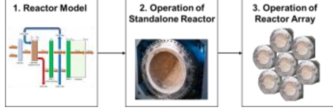
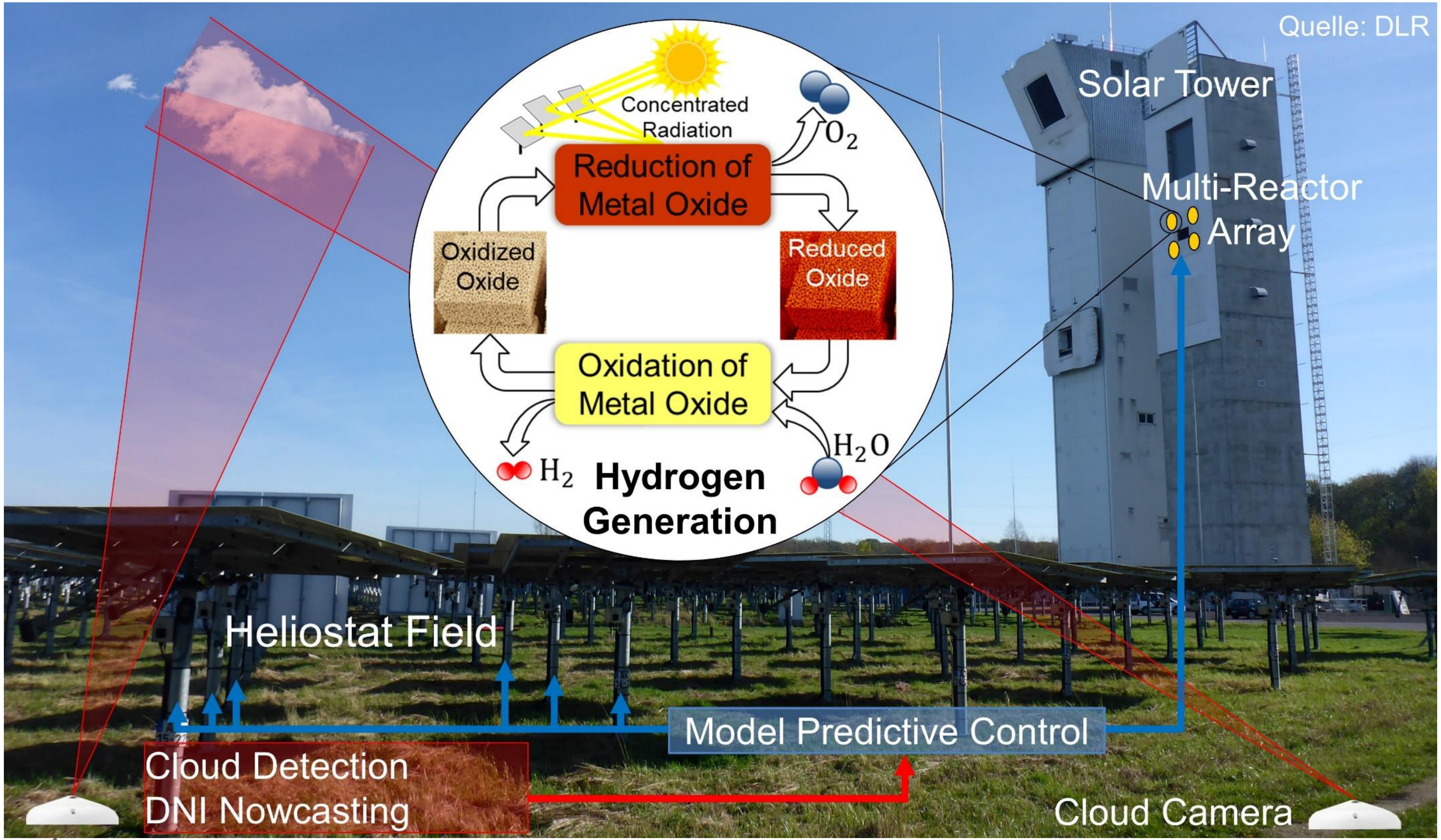


Outlook: Demonstration of Multi-Reactor Control Strategy



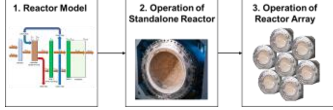
Project SolarFuelNow

- Efficient control of solar fuel production by DNI nowcasts
- Model Predictive Control (MPC)
- Integration of irradiation forecast

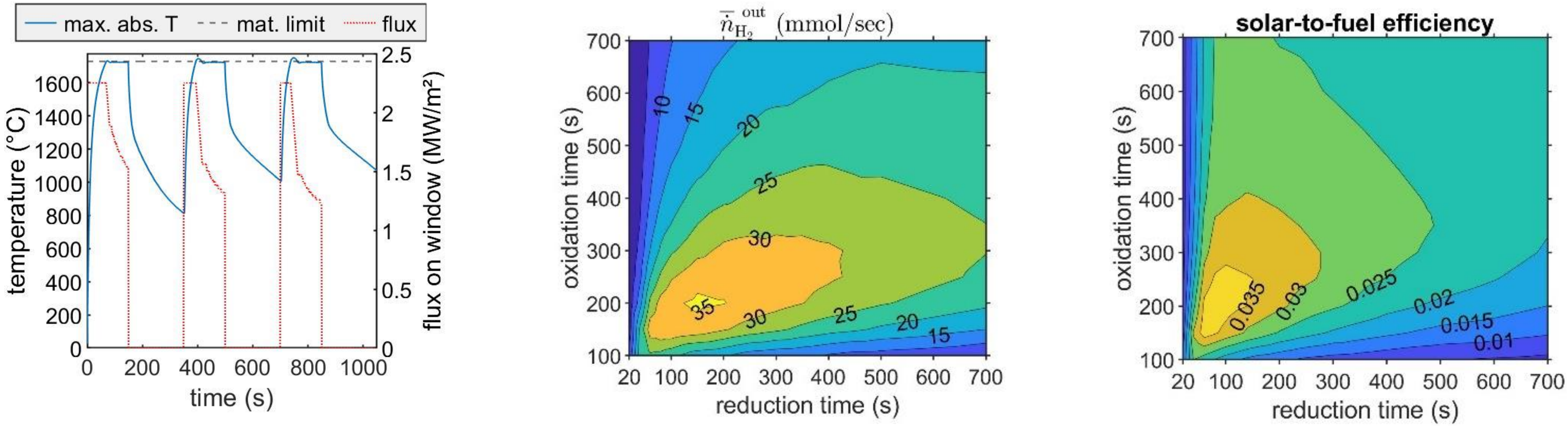
Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages



Outlook: Control by Maximum Absorber Temperature



- Flux is adjusted so that temperature is not exceeding material limit of 2000K
- Higher efficiencies and hydrogen yield for standalone reactor (2.9% → 3.5%)
- Short reduction and oxidation durations
- Multi-chamber optimization is difficult, will be investigated in the future